Slip Determination Method Using MCSA.

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Abstract- **Currently, a number of methods exist to determine the slip in asynchronous motors. In the MCSA analysis it is indispensable to know the motor speed. In this paper a slip determination methodology using stator current is proposed. This methodology is based in the frequency spectrum intensity analysis and the identification of the eccentricity-related component**.

I. INTRODUCTION

The slip can be determined with the use of different types of speed transducers. However, there are some disadvantages for their use at the industrial level, such as lack of simplicity and practicality. Examples of these disadvantages are the need of installation, calibration and maintenance. An additional disadvantage that must be considered is that the cost of transducers can represent a significant percentage of the motor cost [1] [2].

The knowledge of the rotor speed is essential for the proper implementation of the different control techniques. During the past forty years several techniques have been proposed in order to determine the slip using only electrical current and voltage measurements [1][2]. By the identification of the introduced harmonics into the stator current by the rotor slots it is possible to determine the motor slip. Thus, the use of a transducer is not required, avoiding the unwanted disadvantages. Another advantage of this method is that the determination of the rotor speed is independent from the electromagnetic parameters variations, depending only of the mechanical structure of the motor [1-4].

The analysis of induction motors by MCSA requires precise knowledge of the motor slip in order to make an accurate diagnosis [5-7]. Commonly, the only motor known data comes from its characteristic data, making it impossible to use the harmonics introduced by rotor slots. This paper proposes a methodology for determining the rotor speed based on the analysis of the frequency spectrum of the stator current. Finally a series of tests carried out in order to corroborate the methodology developed.

II. ECCENTRICITY

There are two types of air gap eccentricity: the static air gap eccentricity and the dynamic air gap eccentricity. In the case of the static air gap eccentricity, the position of minimal radial air-gap length is fixed in space. For example, static eccentricity can be caused by the ovality of the core or by the incorrect positioning of the stator or rotor at the commissioning stage. In the case of the dynamic eccentricity the center of the rotor is not at the center of rotation. Hence, the position of the minimum air-gap rotates with the rotor. For example, dynamic eccentricity can be caused by a bent rotor shaft, wear of bearings, misaligned bearings, mechanical resonances at critical speed and so on [5].

The frequency components in the stator current of an induction machine which are due to air gap eccentricity can be obtained as:

$$f_{ec} = f_1 \pm k.f_{rm} \qquad (1)$$

Where,

f_{ec} = eccentricity frequency
f_1 = supply frequency
f_{rm} = rotor mechanical frequency
$k = 1,2,3...$

III. SLIP ESTIMATION METHODOLOGY

In this section, a slip estimation methodology using the frequency stator current spectrum is presented. The main objective is to identify the frequency component associated to eccentricity in order to obtain the rotor speed [9].

First, the motor nominal speed must be known in order to determine the frequency range in which the eccentricity component can be found. Then the frequency component associated to the eccentricity fault is calculated using (1) and the value of the nominal rotor speed.

$$f_{ecn} = f_1 \pm f_{rmn} \qquad (2)$$

Where,

f_{ecn} = nominal eccentricity frequency
f_1 = supply frequency

f_{rmn} = rotor mechanical frequency

It is important that $k = \pm 1$ is chosen, given that the range in which the eccentricity frequency can be found is minimized.

After the motor's nominal eccentricity frequency calculation, the motor current is determined, in order to specify if the eccentricity frequency (f_{ec}) is lower or higher than the nominal eccentricity frequency (f_{ecn}). For example, with $k = -1$, if the motor current is higher than the nominal current, then the eccentricity frequency is lower than the nominal eccentricity frequency. Table 1 shows the relationship between intensity, eccentricity frequency and rotor mechanical frequency and their nominal values.

TABLE I

$k = 1$		$k = -1$	
$I > I_N$	$I \le I_N$	$I > I_N$	$I \le I_N$
$f_{ec} < f_{ecn}$	$f_{ec} \ge f_{ecn}$	$f_{ec} > f_{ecn}$	$f_{ec} \le f_{ecn}$
$f_{rm} < f_{rmn}$	$f_{rm} \ge f_{rmn}$	$f_{rm} < f_{rmn}$	$f_{rm} \ge f_{rmn}$

Where I is the measured current and I_N the nominal current.

Then, to narrow the range of values where the component associated to eccentricity can be found, reasonable limits for the motor speed have been established. For example, in a motor with two pairs of poles, the maximum possible rotor's mechanical frequency is 25 Hz ($1500 rpm/60$). Working with $k = -1$ it is possible to establish a minimum bound for the eccentricity frequency.

$$f_{ec}(\min) = f_1 - f_{rm}(\max) \tag{3}$$

When the current measured is greater than its nominal value (the rotor's speed is less than its nominal value), the eccentricity frequency is bounded as follows:

$$f_{ec}(\min) \le f_{ec} \le f_{ecn} \tag{4}$$

If the nominal speed is 1435 rpm and the supply frequency is 50 Hz, the eccentricity frequency will be in a 1.08 Hz wide window.

$$25Hz. \le f_{ec} \le 26.08Hz. \tag{5}$$

If the stator current is higher than the nominal ($f_{rm} < f_{rmn}$), for setting a maximum limit for the eccentricity frequency a minimum rotor speed should be set. In this work the maximum slip limit was taken as 5%, other slip values could be considered depending on the case [1]. Thus, the eccentricity frequency component will be located within the following range of frequencies.

$$f_{ecn} < f_{ec} \le f_{ec}(\max) \tag{6}$$

Where the $f_{ec}(\max)$ calculation is based on the consideration of 5% as the maximum slip. For example, if a motor with two pairs of poles, a nominal speed of 1435 rpm and a supply frequency of 50 Hz is considered, the eccentricity frequency is bounded as follows:

$$26.08Hz < f_{ec} \le 26.25Hz \tag{7}$$

The eccentricity frequency can be found inside a 0.17 Hz frequency window, this allows an almost immediate identification. When the samples have a length of 8 seconds, the frequency resolution is 0.125 Hz. This makes possible an accurate identification of the eccentricity's frequency component.

Another important thing is that leakage doesn't represent a problem, since the eccentricity frequency is far enough from the supply frequency associated component.

Once the discrete frequency component associated to eccentricity is calculated, its exact frequency has to be determined. Being a_k the k-th harmonic associated to the discrete Fourier Transform (DFT) and tm the sampling time, the eccentricity frequency is determined as follows:

$$f_{ec} = \frac{k \pm \frac{1}{1+\Psi}}{tm} \tag{8}$$

Where

$$\Psi = \frac{|a_k|}{Max(|a_{k+1}|,|a_{k-1}|)} \tag{9}$$

Being a_k the main harmonic associated with the eccentricity frequency. It is important to say that (8) is valid when there are no other components due to different causes next to the interest component, and that no windows functions are used.

Finally, once the frequency associated to eccentricity determined, it is possible to find from (1) the rotor mechanical frequency and so, the slip.

IV. SLIP ESTIMATION EXAMPLES:

In this section an example of a slip estimation using the methodology described above is presented. For this test, M1 motor (see Fig. 1) with its nominal data shown in table 2 was used.

TABLE 2
MOTOR CHACTERISTICS

Motor: M1	
Triangle:	Star:
230 v	380 v
15 A	8.6 A
Power:3 HP	
Rpm:1435	
Pole pairs:2	
Frequency: 50 Hz	

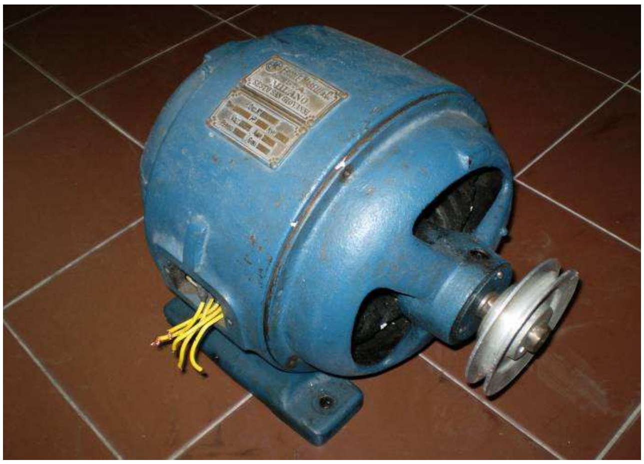

Fig. 1. Tested motor.

First, knowing that the supply frequency is 50Hz ($k=-1$ is used) the nominal eccentricity frequency is calculated.

$$f_{ecn} = 50 - \frac{(1435)}{60} = 26.08 \text{ Hz.} \qquad (10)$$

Then, from the measured and nominal current the frequency range in which the eccentricity component can be found is determined.

The measured current is $9.3A_{rms}$ and the nominal value is $8.6A_{rms}$. Knowing this, it is possible to say that the motor mechanical frequency is lower than the nominal. Hence, using the 5% maximum slip criteria, the eccentricity frequency is bounded as it follows:

$$26.08Hz < f_{ec} \le 26.25Hz \qquad (11)$$

Taking a sample time of 8 seconds the following spectrum near the interest frequency was obtained.

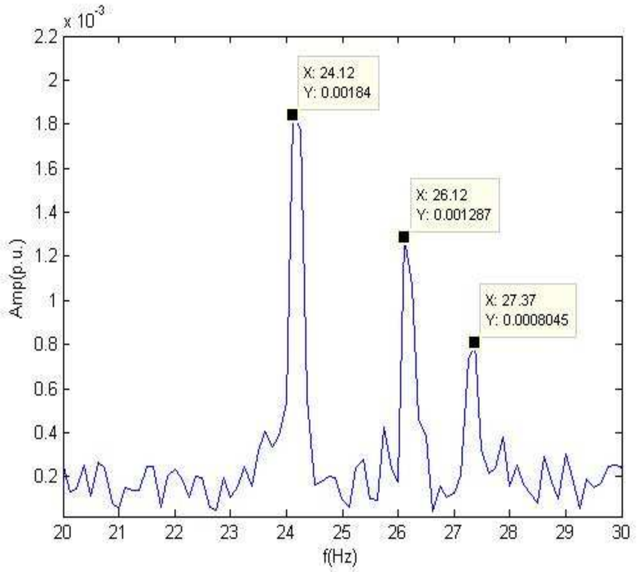

Fig. 2. Current spectrum.

Knowing that the interest component is in the environment set by (11), it is easy to obtain the frequency component associated to eccentricity. Then, from (8) and (9) it is possible to obtain the exact frequency.

$$\Psi = \frac{0.001287}{0.00107} = 1.2028 \qquad (12)$$

$$k = 26.12 * 8 = 208.96 \qquad (13)$$

$$f_{ec} = \frac{k + \frac{1}{\psi + 1}}{tm} = \frac{208.96 + \frac{1}{1.2028 + 1}}{8} = 26.18Hz \quad (14)$$

Knowing the eccentricity frequency, the slip determination cab be achieved:

$$f_{rm} = 50 - f_{ec} = 23.82Hz$$

A motor speed of 1429.2 rpm and a slip of 4.7% was obtained. The result was then verified using an optical tachometer.

Bellow another test made in an extruder motor is exposed.

TABLE 3
MOTOR CHACTERISTICS

Motor: M2	
Triangle:	Star:
230 v	380 v
590 A	340A
Power:300 HP	
Rpm:960	
Pole pairs:3	
Frequency: 50 Hz	

Firstly the nominal frequency is calculated.

$$f_{ecn} = 50 - \frac{960}{60} = 34Hz \qquad (15)$$

The measured current is bellow the nominal current.($I = 246A_{rms}, I_N = 340A_{rms}$), thus the eccentricity frequency is bounded as follows.

$$f_{ec}(\min) \leq f_{ec} \leq f_{ecn} \qquad (16)$$

With,

$$f_{ec}(\min) = 50 - \frac{1000}{60} = 33.3Hz \qquad (17)$$

Therefore

$$33.3Hz \leq f_{ec} \leq 34Hz \qquad (18)$$

Analyzing the current spectrum (Fig. 4) it is possible to calculate the eccentricity frequency and thus determine slip.

$$\Psi = \frac{0.2602}{0.2585} = 1.2028 = 1.01 \qquad (19)$$

$$k = 33.41 * 8 = 267.28$$

V. CONCLUSIONS

In this paper a methodology for slip determination using stator current is proposed. This methodology is based in the fact that eccentricity causes certain characteristic components in the stator current of induction machines. This makes it possible to determine easily and accurately the rotor speed. This methodology has been successfully applied in the laboratory tests presented here. But there are some limitations of this method that should be taken into account. The method presented requires that the motor is under normal operating conditions and that there are no other components in the stator current that mask eccentricity fault harmonics.

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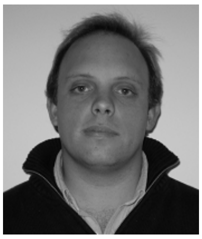
VII. BIOGRAPHIES



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